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MEASURING SYSTEMS FOR TESTING THE SAFETY AND SECURITY OF RAILWAY VEHICLES

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Abstract: *The paper presents the measuring systems for testing the safety and security of railway vehicles that are in recent few years developed and built in the Center for Railway Vehicles at the Faculty of Mechanical Engineering Kraljevo. The measuring systems are based on wireless signal transmission and allow testing of quasi-static and dynamic characteristics of railway vehicles in accordance with UIC 518 regulations– quiet running and running safety of railway vehicles and UIC 530-2 – Wagons – Running safety (Testing the railway vehicles behavior in repression through the S curve). The following topics are presented in this paper: the measuring system for measurement of lateral force Y and the vertical force Q that occur in contact between wheel and rail, as well as their ratio Y/Q; the test stand for calibration and testing of instrumented wheelsets; the measuring system for measurement of lateral force H and acceleration in the height of axle-box; the measuring system for measurement of the height of wheel lifting; the measuring system for measurement of acceleration of the wagon body; the measuring system for measurement of compressive force at the autocoupler; the measuring system for measurement of lateral movement between wagons; and the measuring system for measurement of temperature in the axle-box. For all measuring systems special software is developed, that allow easy control and adjustment, as well as visualization and storage of obtained measurement results.*
Key words: *Measuring systems, testing, railway vehicles, safety, security*

1. INTRODUCTION

One of the main directions of future development of railways is based on a constant tendency to increase security and speed of movement of railway vehicles, both of passenger and freight traffic. In addition, significant aspects of future development of railways are oriented towards optimization, introduction of new materials, reducing negative environmental impact, etc. According to such trends of further development, among the most important issues are troubleshooting safety and security of the most responsible parts of railway vehicles. It is well known that the failure of parts such as wheels, axles, or bearings, leads to failure of not only given wagon, but in most cases of the whole train. The consequences are devastating, with great material damage, and in many cases with human victims. Therefore, the issue of increasing safety and security or preventing the failure is given the special attention, and it is solved in different ways. One way refers to the analysis and identification of the causes that lead to failure and their removal in the phase of design and construction of railway vehicles. In addition, there are different types of technical reviews and inspections, and preventive maintenance of vehicles in the exploitation phase during its life cycle. One of the most important ways to increase safety and security is the development and introduction of systems for continuous monitoring of components of railway vehicles. On-line monitoring of wheelsets condition is of utmost importance, as well as forces in the wheel-rail contact and their ratio, temperature in the axle-boxes, and track condition. In this way it is possible to detect the error immediately upon its genesis and the timely response to prevent the incident.

The main precondition for solving the problem of increasing safety and security of railway vehicles is a good knowledge of their dynamic behavior. The best way to identify the dynamic behaviour of railway vehicles is a combination of theoretical and experimental approach. Experimental tests in combination with the application of theoretical methods is a basic prerequisite for the process of quality development and design of new types, or changes of performance and improvements to existing types of railway vehicles [1–6]. This leads to the identification of the dynamic behaviour of railway vehicles which is based on scientific assumptions and that allows the description and explanation of existing phenomena. Therefore, experimental tests in the process of identifying the dynamic behaviour of railway vehicles, as well as in developing ways to increase safety and security have an enormous importance. In addition, in the process of certification of all newly-designed types of railway vehicles performing experimental tests is mandatory according to the relevant international standards that treat this area such as UIC, TSI, EN, ERRI, etc. Based on the results of experimental tests it is estimated whether the vehicle complies with the requirements from the standards and whether it can be included into commercial rail traffic. Among the most important experimental tests of railway vehicles are examination of quiet running and running safety [7] and testing the railway vehicles behavior in repression through the S curve [8]. In the laboratory of the Center for Railway Vehicles at the Faculty of Mechanical Engineering Kraljevo the measuring systems that allow performing most of the experimental tests according to the standards [7] and [8] are developed. Most of the measuring systems were developed as part of the implementation of FP-7 project ''Strengthening Railway Vehicles Centre of Faculty of Mechanical Engineering Kraljevo – SeRViCe'' [9], funded by the European Commission and the Ministry of Science of Serbia. This paper in sections provides an overview of developed and produced measuring systems, focusing on their principle of operation, components and basic technical characteristics.

2. THE MEASURING SYSTEM FOR MEASUREMENT OF FORCES IN THE WHEEL-RAIL CONTACT

This measuring system is designed for continuous measurement of lateral force *Y* and the vertical force *Q* that occur in contact between wheel and rail and it is characterized by the wireless transmission of signals. The system is based on measuring of deformation of the wheel using the strain gauges placed at the specially selected points, then digitizing the measuring signal, radio transmission to the static electronic module placed in the box in the measuring wagon, as well as the appropriate processing of received signals to calculate the values of the force components *Y* and *Q*. The main components of the system are: two instrumented wheelsets, electronic computer unit for receiving and storing signals, and computer module for procession and presentation of measurement results. These components are interconnected through a wireless ethernet network that enables their communication (Fig. 1).

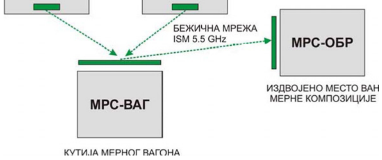

Fig.1 Block diagram of the measuring system for measurement of *Y* and *Q* forces

The instrumented wheelset is based on a wheelset manufactured by the Czech Bonatrans whose carrying capacity is 22,5 t. The wheels are equipped with strain gauges whose purpose is to measure the deformations caused by the action of vertical and lateral forces (Fig. 2).

Fig.2 Instrumented wheelset

The positions of placing strain gauges are determined based on the FEM calculation of deformation of the wheel. The measuring points are distributed at 8 equally distant positions on the wheel perimeter, with the angular distance of 45°, and the strain gauges are grouped in four perimeters at different radial distances. Two groups, each with 8 strain gauges, at one diameter are installed on the external side of the wheel, and two groups on the internal side of the wheel (Fig. 3).

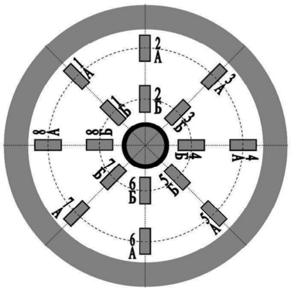

Fig.3 Distribution of strain gauges on one side of the wheel

By connecting the strain gauges in the branches of the Wheatstone's bridge the maximum sensitivity is provided. The transmission of measurement data from the rotating axle to the box in the measuring wagon is performed by radio link by means of a special electronic module. Power supply of complete measuring system is performed through an appropriate module which provides a nominal voltage of 7.2 V, and is based on the basis of 12 re-rechargeable battery cells. This battery module is mounted on a rotating axle through a special mechanical carrier that allows easy assembly and disassembly.

The electronic-computer unit for receiving and storing signals during measurement is placed in the box inside the measuring wagon. The main part of this unit is a personal computer which operates under the operating system Windows, which is the central part of the LAN ethernet network. The LAN ethernet network allows collection of signals from the instrumented wheelsets, as well as accelerometers, wheel lifting converters and other sensor elements.

The computer module for procession and presentation of measurement results (Fig. 4) can be located at a separate place outside the measuring wagon or inside of measuring wagon. This module in real time receives measurement results from the storing unit and processes them in the appropriate way and shows the measurement results.

Fig.4 Computer module for procession and presentation of measurement results

For this measurement system a special software package was developed which is used for adjustment of parameters connected with acquisition of signals from strain gauges, such as resolution and speed of conversion, offset and signal intensification, temperature compensation, etc.

3. TEST STAND FOR CALIBRATION AND TESTING OF INSTRUMENTED WHEELSETS

The main purpose of the test stand is calibration and testing of instrumented wheelsets of railway vehicles in quasi-static and dynamic operating modes [10]. The test stand provides an important opportunity to work with instrumented wheelsets in the laboratory conditions at minimal costs of testing. The basic function of the test stand is to provide the contact between wheel and rail, as well as to give an opportunity for on line measurement of *Y/Q* ratio. The basic parts of the test stand are (Fig. 5): 1 – Down wheelset; 2 – Horizontally motional carrier of down wheelset; 3 – Top wheelset (wheelset that is calibrated – tested); 4 – Vertically motional carrier of top wheelset; 5 – Supporting construction; 6 – Hydraulic systems for setting forces Y and Q; 7 – Systems for registering the values of given forces Y and Q; 8 – Drive movement; 9 – Safety and security systems; and 10 – Control console.

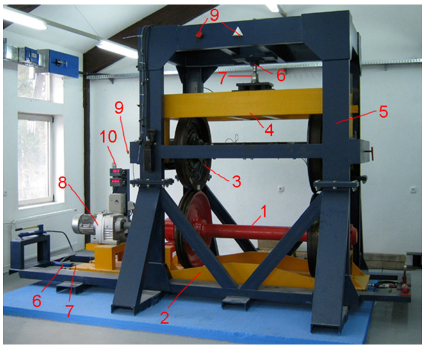

Fig.5 Test stand for calibration of instrumented railway wheelsets

The role of the rail is accomplished using by the down wheelset, while the function of the wheel is performed by the top wheelset which is calibrated. The down wheelset is specially processed so that its radius of the wheel profile corresponds to the radius of the head of the rail profile (Fig. 6).

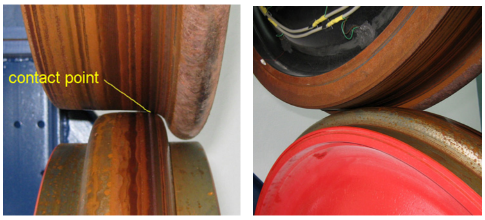

Fig.6 Wheel-rail contact on the test stand

The characteristic movements are: horizontal movement of the down wheelset that represents the rail, and vertical movement of the top wheelset which is tested (calibrated). By action of the hydraulic cylinder on a horizontally motional carrier, the entire system together with the down wheelset is actuated and creates a horizontal force *Y* in contact between the wheel of the calibrated wheelset and wheel of the down wheelset. By action of the hydraulic cylinder on a vertically motional carrier, the entire system together with the top calibrated wheelset is actuated and creates a vertical force *Q* in the same contact. In this way it is performed a laboratory investigation of forces in the contact between the wheel and rail that occur during the movement of railway vehicle on the track. Forces can set independently of each other, and the system allows changing the location of the contact point on the tread surface of the wheel. The test stand allows the setting of forces in vertical direction up to 225 kN, and in the horizontal direction up to 100 kN. The whole system is designed to calibrate the measurement wheelsets of a normal track with a width 1435 mm, and to work with wheelsets whose carrying capacity is up to 22.5 t. In this way it is possible to measure the deformations (or stresses) of the measurement wheelset in dependence of the predefined *Y/Q* ratio.

The supporting structure of the test stand is composed of steel UNP profiles that are connected with bolted and welded connections. It is designed to provide quality testing and maximum stability of the entire system during the maximal loads and rotating speeds of wheelsets.

For setting the forces *Y* and *Q* in the horizontal and vertical directions the hydraulic cylinders which are driven over the hand pumps are used. These systems allow the assignment of forces up to 100 kN, or 225 kN, respectively. Detection of values of given forces *Y* and *Q* is done using the force converters produced by FLINTEC that are set between the pistons of hydraulic cylinders and constructions of motional carriers of wheelsets. The values of applied horizontal and vertical forces obtained from the force converters are displayed on two digital alpha numeric displays with a precision of ±10 N.

Rotating movement of the tested wheelset is provided indirectly through the down wheelset whose task is to represents the rail. The down wheelset receives the rotating movement across the cardan shaft that is powered by the electric motors with gear. The power of electric motor is 7.5 kW, while speed of rotation is regulated by the frequency regulator. The main electric switch, frequency regulator and the alpha numeric displays for reading the values of forces *Y* and *Q* are placed on a special control console that can be moved in the immediate area around the test stand.

The measurement signal obtained during the calibration is shown in Fig. 7.

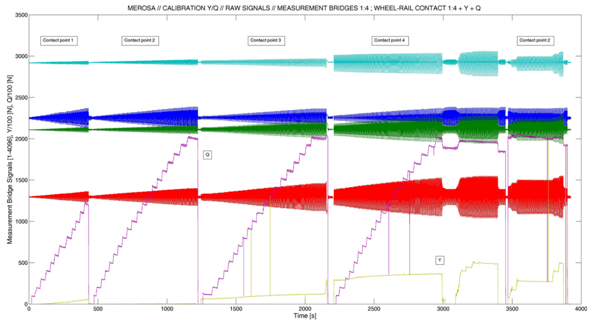

Fig.7 Measurement signal obtained during the calibration

4. MEASURING SYSTEM FOR MEASUREMENT OF LATERAL FORCE AND ACCELERATION IN THE HEIGHT OF AXLE-BOX

The measurement of lateral force *H* and lateral acceleration in the height of axle-box is performed by a special mechanical assembly – converter of *H* force (Fig. 8), on which the strain gauges are installed. The converter is specially designed to allow efficient and linear conversion of the lateral force in the deformation of the sensor element. The two sides of the force converter have installed a couple of strain gauges which are mutually placed at right angles. These four strain gauges forming a full measuring bridge, with maximum sensitivity for measurement of pressure and tension deformations and compensation of all other effects (bending moment, temperature).

The acceleration in the lateral direction is measured by using a special electronic device whose dimensions are 20x10 mm, which is equipped with two-axis accelerometer. Power supply and signal from the accelerometer, power supply of electronic module, power supply and signal of measuring bridge for measurement of *H* force through the 7-pin connector are connected with the corresponding electronic unit.

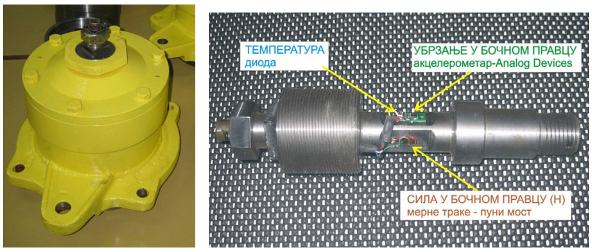

Fig.8 Converter for measurement of lateral force and lateral acceleration

5. MEASURING SYSTEM FOR MEASUREMENT OF THE HEIGHT OF WHEEL LIFTING

This measuring system is used for testing the wagons in repression through the S curve. The mechanical assembly for measurement of the height of wheel lifting (Fig. 9) converts the height of wheel lifting into the angular displacement of the legs which keeps the sliders on the rail, on the front and bottom sides of the wheel. During the wheel lifting, the converter body lifts and the angles of both legs of the rail slider get reduced in relation to the normal.

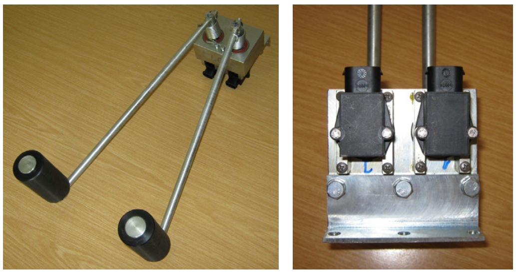

Fig.9 Converter for measurement of the height of wheel lifting

There are two angle converters in the converter, one for each leg, which measure the change of angle. The angle converters have the range of 20 degrees, and they produce analogue stress output in the function of angular position. The sum of signals from these two angle converters are processed in a special software which can accurately determine the height of wheel lifting above the top of rail.

6. MEASURING SYSTEM FOR MEASUREMENT OF ACCELERATION OF THE WAGON BODY

Measurement of acceleration of the wagon body in lateral and vertical directions is performed by means of the calibrated two-axis accelerometer with measurement range ±10 g and the frequency bandwidth 31 Hz. Since these are an analog accelerometer for signal acquisition, digitization and sending to the computer unit for storage, processing and display a special electronic module is used. Block diagram of this measuring system is shown in Fig. 10.

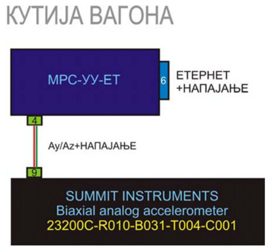

Fig.10 Block diagram of the measuring system for measurement of acceleration of the wagon body

7. MEASURING SYSTEM FOR MEASUREMENT OF COMPRESSIVE FORCE AT THE AUTOCOUPLER

This measuring system is also used for testing the wagons in repression through the S curve. Measurement of compressive forces at the autocouplers is performed using specially instrumented sets of autocouplers type SA-3 (Fig. 11), which are installed on the wagons in front and behind the tested wagon in the test train, during the testing through the S curve.

Fig.11 Instrumented autocouplers type SA-3

Two pairs of strain gauges are installed in the full measuring bridge at one of the autocouplers. Two strain gauges are installed in the direction of elongation at tension, and the other two are normal to the direction of elongation and they are used for compensation. Detection and excitation of the measuring bridge, as well as digitizing and sending a measurement signal is carried out using a corresponding electronic unit. This electronic module is powered from the battery module, and ethernet communication with computer units reailzed using wireless radio links in ISM band with 2.4 GHz.

8. MEASURING SYSTEM FOR MEASUREMENT OF LATERAL MOVEMENT BETWEEN WAGONS

This measuring system is also used for testing the wagons in repression through the S curve. Measurement of lateral movements between test and barrier wagons in test train is based on an optoelectronic vision system and image processing. Two CCD cameras are mounted on the test wagon and pointed towards the front end the rear barrier wagons whose buffers mutual position are to be measured, as shown in Fig. 12.

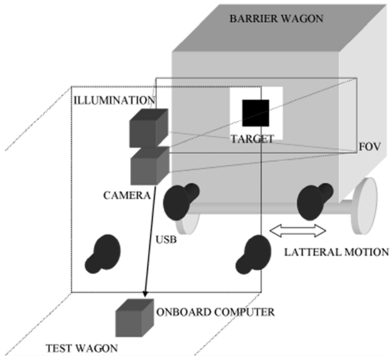

Fig.12 Measuring system for measurement of lateral movement between wagons

An image of the target is acquired by a camera mounted on the front and rear sides of the test wagon. Field of view (FOV) of the camera points towards the target mounted on the barrier wagon whose buffer misalignment is to be measured. This wagon is marked with a cooperative target mounted across the gap and pointing towards camera. Target moves in direction lateral to the track following the motion of the wagon buffers and its image is acquired by the camera, using USB interface and processed by the onboard computer. The position of the target inside the field of view (FOV) of the camera follows relative position of the buffers, and is used to calculate the misalignment.

For this measuring system a special processing software was developed that enables the determination of final target position or value of the lateral movement between the wagons.

9. MEASURING SYSTEM FOR MEASUREMENT OF TEMPERATURE IN THE AXLE-BOX

Measuring system for measurement of temperature in the axle-boxes is based on wireless signal transmission and is designed as a system for on-line monitoring. On each axle-box of the wagon a special sensor units that collect information about temperature is placed (Figs. 13-14). The signals from these units are collected into the two transceiver units mounted on each side of wagons.

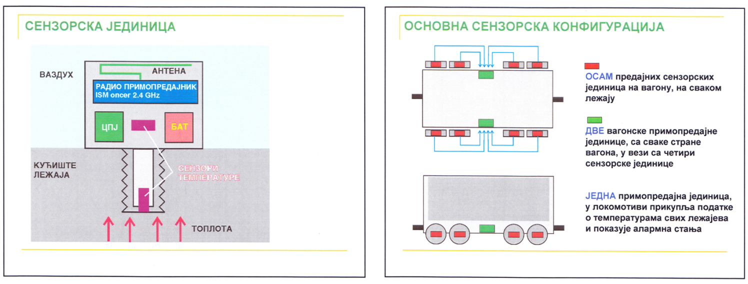

Fig.13 The basic sensor configuration

Fig.14 Preliminary tests

Data from these transceiver units from the wagons are transmitted by wireless via an ethernet connection to the receiving unit in the locomotive, which collects data about the temperatures of all axle-boxes and displays an alarm condition in case of exceeding the normal ranges.

10.CONCLUSION

This paper presents the measuring systems that allow testing the safety and security of railway vehicles, and that are in recent few years developed and produced in the Center for Railway Vehicles at the Faculty of Mechanical Engineering Kraljevo. The developed measuring systems allow testing quasi-static and dynamic characteristics of railway vehicles in accordance with international regulations UIC 518 – quiet running and running safety of railway vehicles and UIC 530-2 – Wagons – Running safety (Testing the railway vehicles behavior in repression through the S curve). All measurement systems are aligned with the leading world trends in this area and their main characteristics is the wireless transmission of signals.

Besides the possibility to perform the above mentioned tests, measuring systems enable scientific research in the field of innovative solutions that are oriented to optimization of components of the railway vehicles, introduction of new materials, reducing environmental impact, etc. It also can be used for research in order to find innovative solutions in the field of increasing safety and security of the most responsible parts of railway vehicles. It is especially topical issue of increasing safety and security of railway vehicles through on-line monitoring of wheelsets condition, on-line monitoring of forces in the wheel-rail contact and their ratio, and on-line monitoring of temperature in the axle-boxes. Through further development and improvement, these measuring systems can be very effectively used for such purposes.

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REFERENCES:

[1] Iwnicki SD, ''Handbook of railway vehicle dynamics'', Taylor & Francis, 2006.
[2] Andersson E, Berg M, Stichel S, ''Rail Vehicle Dynamics'', Railway Group KTH, Stockholm. 2007.
[3] Wickens AH, ''Fundamentals of rail vehicle dynamics'', Swets & Zeitlinger, 2003.
[4] Garg VK, Dukkipati RV, ''Dynamics of railway vehicle systems'', Academic Press, 1984.
[5] Popp K, Kaiser I, Kruse H, ''System dynamics of railway vehicles and track''. Archive of Applied Mechanics, Volume 72, Numbers 11–12, 949–961. doi:10.1007/s00419-002-0261-6, 2003.
[6] Atmadzhova D., A model in studies active steering rotation wheelsets VI International Scientific Conference HEAVY MACHINERY, Kraljevo, Serbia, 2008
[7] Atmadzhova D., An Electronic System for Measuring the Attack Angle of Railway Wheelsets at a Running in Curves. ISSE 2010 WARSAW May 12 – 16 Poland, 2010

[8] Atmadzhova D., Influence of wheel and rail profiles on railway vehicle dynamics, First International Conference on Road and Rail Infrastructure CETRA 2010, 17-18 May, Opatija, Croatia, 2010
[9] Atmadzhova D, ''The Wheel Flat – Rail Interactions''. Proceedings of the 7th Triennial International Conference Heavy Machinery – HM 2011, Vrnjacka Banja, Serbia, No 1, pp. 1–8, 2011.
[10] UIC CODE 518 OR, ''Testing and approval of Railway vehicles from the point of view of their dynamic behavior – Safety – Track fatigue – Running behavior'', 4th edition, 2009.
[11] UIC CODE 530-2 OR, ''Wagons – Running safety'', 6th edition, 2008.
[12] Šoškić Z, Petrović D, Bogojević N, Rakanović R, ''FP7 project SeRViCe – Support to Reinforcement of Railway Research Potential of Serbia'', Proceedings of the second international Railway Symposium IRS Turkey, Istanbul, pp 1147, 2008.
[13] Milan Bizic, Milos Tomic, Zoran Djinovic, Dragan Petrovic, ''Test stand for calibration of measurement railway wheelsets'', Proceedings of the 7th international conference research and development of mechanical elements and systems – IRMES, Zlatibor, Serbia, pp. 419-424, 2011.

СИСТЕМИ ЗА ИЗМЕРВАНЕ И ИЗПИТВАНЕ БЕЗОПАСНОСТТА И СИГУРНОСТТА НА ЖЕЛЕЗОПЪТНИ ПРЕВОЗНИ СРЕДСТВА

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Ключови думи: *Системи за измерване, изпитване, железопътните превозни средства, безопасност, сигурност*
Анотация: *Докладът представя измервателни системи за изпитване безопасността и сигурността на железопътните превозни средства, които през последните няколко години са проектирани и изградени в Центъра за Железопътни возила към Факултета по машиностроене гр.Кралево. Измервателните системи са базирани на безжично предаване на сигнала и позволяват регистрирането и измерването на квази-статичните и динамичните характеристики на железопътните превозни средства в съответствие с изискванията на международните нормативи – фишове на UIC 518 – плавност на хода и безопасно движение на железопътни возила и UIC 530-2 - Вагони - безопасност (Изпитване на железопътните превозни средства и преминаване през S кривина). В този доклад са представени следните теми: система за измерване на напречната сила Y и вертикална сила Q, които се реализират в контакта между колело и релса, както и тяхното съотношение Y/Q; изпитателен стенд за калибриране и изпитване на измервателни колооси; измервателна система за измерване на напречната сила H и вертикалните ускорения на букси; измервателна система за измерване на височината на повдигане на колело; измервателна система за измерване ускоренията на коша на вагона; измервателна система за измерване на сила на натиск в автосцепка; измервателна система за измерване на странично движение между вагоните, както и система за измерване на температурата в буксите на колоосите. За всички системи за измерване е разработен специален софтуер, които позволява лесно управление и настройка, както и визуализация и съхранение на получените резултати от измерването.*